FINAL REPORT

Covering the Official Contract Period

14 July 1964 - 31 December 1966

(including subsequent developments up to the present, related to the contract)

MODIFICATION OF 82-INCH COUDE SPECTROGRAPH AT McDONALD OBSERVATORY

Contract NASr-230

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I. Introduction

In the United States, there are only five large-telescope coude-spectrograph combinations suitable for research on the planets by high-resolution spectroscopy. In particular, the telescopes associated with these spectrographs have many other uses, and have seldom been assigned to planetary studies. Also, in the case of the 82-inch Struve Reflector of the McDonald Observatory, the lack of assignment to planetary spectroscopy in the past had stemmed largely from instrumental inadequacies.

The principal purposes of this contract were to correct the problems associated with the existing large coude spectrograph of the telescope, to add certain auxiliary instruments to it, and to demonstrate its improved capability for planetary work in preparation for observations of Mars and other planets.

During the two initial NASA-funded years of the contract, and the third-year extension at no additional cost to NASA, significant additional University contributions of manpower and funds made it possible to complete the essential schedule of work even though costs proved somewhat greater than estimated in the original proposal.

In this final report, the principal troubles to be corrected and the actions taken are briefly reviewed, followed by a summary of initial results achieved with the new spectrograph and accessories.

II. Problems and Corrective Actions

1. Spectrograph placement and configuration.

Several of the basic problems with the spectrograph arose from compromises forced on its original design fifteen years ago by the excessively small budget available to Dr. W. A. Hiltner, its designer. In particular the space into which the instrument could be fitted was sharply restricted to a ten-foot length between the south pier of the 82-inch reflector and an open strip four feet short of the south dome wall--the strip being reserved for travel of a stair rotating with the dome. In order to have the largest possible spectrograph, short of rebuilding some portions of the dome, the entrance slit assembly was set right against the massive south pier, leaving only about a four-inch space in which to place or gain access to the slit, filters, comparison source, and guiding systems; this arrangement required pre-slit equipment such as image rotators to go into an almost completely inaccessible polar axis tube lying within the concrete south pier.

The problems of access were serious enough to discourage use of the spectrograph, and to prevent the insertion of any but the barest of slit instrumentation.

To correct this situation, it was necessary to move the spectrograph back away from the south pier. In turn, this required the construction of an elevated cat-walk fully around the inside of the dome, with several fixed stairs, to give access to the prime focus stations; the fixed cat-walk eliminated the moving stair with its requirement for open space around the entire inner wall of the dome. Pushing the spectrograph farther down the coude beam, which is inclined at the polar axis angle, also required cutting a large hole in the existing steel floor, and lowering the floor in that section by several feet. This in turn required that the ceilings of the offices below be refinished. Finally, the move also required that the old observing room and its thermal shell be demolished. The new spectrograph room not only offers easy access to the instrument, with excellent insulating properties, but also provides three satellite rooms, respectively for the observer at the slit, for plate-loading, and for coude electronics. These extensive rebuildings constitute what we have called the "external changes" to the spectrograph; most of the other changes were at least partly conditional on the completion of the external work. Accordingly, it was undertaken first, and completed in the late autumn of 1964, shortly after the contract was awarded.

III. Optical Refiguring

A second reason for lack of use of the coude spectrograph was the extremely poor image quality at the coude focus. Nor was any information available as to the intrinsic quality of the coude optics.

To correct these situations, services were engaged of Jean Texereau, Principal Optical Engineer at the Paris Observatory and perhaps the most skillful and experienced of living astronomical opticians. Texereau spent four months with the telescope, during which time he improved the support of the primary mirror, and refigured and remounted the mirrors bringing the light to the coude focus; as a result he improved the best-available image from about three seconds of arc to better than one-tenth second of arc, as shown in photographs in previous reports (copy appended to this final report). For work on objects of small size, the improved image is necessary to achieve efficient use of the spectrograph; for work on objects of large angular size such as planets, the high-quality images now make it possible to work on individual elements of a planet rather than on an integrated blur of light.

Texereau also investigated the coude optics. He found that, while these could be improved (a program which we still intend to take up as time and funding may permit), they are adequate to be used with reasonable performance, even with a substantially enlarged collimated beam. Accordingly no changes have yet been made in the internal optical surfaces of the coude cameras (changes in collimator and gratings are noted below).

IV. Entrance Slit Assemblies

In view of the inadequate space of the older spectrograph arrangement, there was essentially no equipment at the slit of the spectrograph. After moving the spectrograph, it became possible to utilize the space of nearly three feet between the concrete south pier of the telescope and the spectrograph slit. A large new slit plate and an equipment base were prepared, with T-slots for mounting auxiliary equipment. Fitted to these plates are now:

a. A quick change mechanism to remove and reinsert the slit itself
b. An image rotator
c. An improved guiding system
d. An improved comparison source input system
e. A new filter holder
f. Attachments for various planetary cameras

These changes have helped to make the coude spectrograph so easy and efficient to use that the telescope is now at this configuration nearly half the time, instead of rarely as before; still other forms of observational equipment are being designed to utilize the space provided.

V. Internal Changes

The spectrograph in its older form was relatively inefficient because it had a remarkably small collimated beam for a coude spectrograph (only three and a half inches), and because only a single and relatively old grating was available. Both the speed and the resolution of the instrument could be sharply increased by enlarging the size of the collimated beam and by providing a wider range of gratings. For these changes to be possible, the steel frame of the spectrograph had to be rebuilt. In particular, it was necessary for (1) the rails to be extended, (2) new support points to be provided, (3) some of the internal frame to be removed and other elements added to provide the space for the new collimator, (4) the grating-holder assembly to be removed and rebuilt to permit use of larger gratings and relative easy change of them, and (5) the optics to be removed in order to open out the holders for the Schmidt cameras to permit the passage of the new five-and-a-half inch collimated beam.

The changes connected with the gratings were carried out by early 1965, and three excellent new 6 by 8-inch Bausch and Lomb replica gratings were installed. The spectrograph was used in this form for a bit more then a year, until the summer of 1966 when the other internal changes were executed. In particular, the new and larger off-axis collimator was fabricated in the optical shop of the Lunar and Planetary Laboratory, and the other changes were made in the spectrograph as outlined above. These did result in the expected near-doubling of speed and of resolution.

VI. Coude Scanner

Dr. Robert Tull designed and saw to the construction and installation of the new coude scanner, as reported in detail in a previous Quarterly Report. This involved construction of a substantial mechanical bracket system within the spectrograph, and the installation of a device to select through exit slots a portion of the highest-dispersion spectrum produced by the camera, with an optical train producing a scanned beam as little as a fraction of an angstrom in wave-length range, to be compared simultaneously against a wider portion of the spectrum using another photocell. In order to avoid the noise produced by Cerenkov flashes in a glass or quartz scanning tube (as is the case with the Mt. Wilson coude scanner of Oke), a mirror arrangement produces the scanning mode over the relatively short wave-length range to be studied with this high-dispersion scanner during each observational run. The scanner is in principle capable of working in the infrared as well as at shorter wave lengths, although the necessary cooling arrangements for the infrared cells are not yet convenient.

The scanner works well with a single input slit, but is relatively slow in this configuration because so little light enters the slit in the high-resolution mode. A Bowen-type image slicer has been constructed, but this design of the slicer has led to difficulties which only now are becoming fully clear, stemming from the fact that the Bowen slicer produces a slightly different primary focal position for each of the broken-up slit elements, sharply decreasing the throughput of light for a narrow slit. The present system also images them onto significantly different portions of the photocathode, rendering the entire system remarkably sensitive to seeing and guiding vagaries. Tull is now working along several lines to make the scanning system more efficient, and believes that better than an order of magnitude improvement should be possible.

VII. Image Tubes

In the summer of 1966 arrangements were built into the coude frame to permit the mounting of an image tube at the A-camera focus, the light being reflected into the image tube though a 45° mirror blocking only a small part of the collimated beam. Apart from resolution difficulties, the Carnegie-RCA image tube arrangements have been very successful. In the blue (S-20 cathode), they produce about ten times shorter exposures then is true for the fastest photographic plates, but the resolution is down by a factor of three, meaning that a camera with shorter focal length could be used to record the same information in about one-tenth the time, thus largely nullifying the speed gain of the tube. But as image tubes with better resolution become available they will take over from photography the recording of high-dispersion coude spectra, at least over limited spectral regions. The same general statements are true for an S1 (infrared sensitive) image tube obtained in the spring of 1967 for the spectral region up through 9,000 Å, but from there on up to 13,000 Å the image tube stands in a class by itself, in view of the extremely low quantum efficiency of photographic emulsions out to 11,000 Å, and their non-availability beyond that limit. In particular, high-dispersion infrared photographic spectra of Mercury and Venus have been obtained at 12,000 Å for the first time. Arrangements are now being made to use the image tubes in the intermediate-focus B-camera, which should extend this infrared work to objects ten times fainter than Mercury and Venus (e.g. Mars). In addition, a separate image-tube development program has been undertaken, which we hope will solve the problem of resolution at least in the blue.

VIII. Miscellaneous

Many lesser associated improvements have been carried out or begun, including realuminization of the optics, provision of appropriate shielding for various critical parts of the light beams, addition of a Hartmann-screen arrangement for focusing, etc. A project so far not carried out has been the improved calibration slits; these were designed and submitted for bids, but all bids were returned far too high. When time permits, a suitable device will probably be constructed in our own shops, to use along with an improved plate holder which will employ photometric calibration strips on either side of the spectrum.

IX. Further Improvements Being Considered for the Spectrograph System

An improved finding system is needed to make it easier to work on relatively faint objects. A semi-automatic planetary camera has been designed and partially constructed, making it possible for a coude observer to take advantage of moments of unusually good seeing to photograph planets while guiding during spectroscopy. As noted above, several of the coude mirrors should be refigured, during some interval when the spectrograph is not otherwise in high demand. To take advantage of the electronographic image tubes which we hope to have within a year, with resolutions higher than those of photographic plates although with rather small photocathodes, an echelle dispersing system is probably required; some prelimary design work has been undertaken. A Fabry-Perot interferometer is being designed for the input slit assembly, to make possible extremely high resolution studies of specific spectral features. Serious consideration has been given to the possibility of building still another extension to the coude room to house a substantial interferometer along the general line of the Connes'. Some of these developments are now being undertaken in a modest way by the University or other sources; several of them may become the subject of new requests for support.

X. Results Obtained with the Improved Spectrograph

Almost entirely as the result of the NASA support, permitting these truly major changes and improvements, it has become both possible and scientifically profitable to devote a substantial fraction of the observing time of the 82-inch Struve reflector to planetary problems in 1965 and 1966, and continuing. Many hundreds of hours have been available for observations of Mars, primarily toward determining the CO_2 abundance, surface pressure, and water vapor content of the atmosphere. Planetary astronomers using the equipment have come from other institutions as well as Texas. Spinrad (Berkeley), Schorn and Moore (JPL), and Owen (Arizona) have been the principal users of the coude spectrograph on Martian problems; one of our graduate students (E. Barker) has not only worked in carrying out the various changes described in this report, but has also become one of the most effective users of the instrument on Martian problems (the subject of his doctoral dissertation). Work is now under way to look for seasonal and positional variations of carbon dioxide and water vapor over the surface of the planet.

Venus has also been extensively observed, mainly by Gray of Texas and JPL, and by Owen and Schorn. The principal results so far concern the temperature structure and the apparent absence of water vapor in the Venus atmosphere. Jupiter has been observed mainly by Owen, who is interested in the abundance of molecular hydrogen, in the attempt to detect duterium, and in the identification of other substances in the Jovian atmosphere. Mercury has been observed mainly by Smith, with results establishing nearly a one-hundred-fold reduction in the upper limit on any possible CO_2 atmosphere (now no more than .04 millibars of CO_2). Extensive planetary patrol photography has been carried out by Capen (JPL), and with a more strongly astrophysical approach by Morrison (of Harvard, conducting his dissertation work under Sagan). A large amount of photographic and spectroscopic material now exists and will be the subject of papers for some time to come. Publications so far directly attributable to this contract are as follows:

Owen, Tobias, 1966, The Composition and Surface Pressure of the Martian Atmosphere: Results from the 1965 Opposition, Ap.J., 146, pp. 257-270

Spinrad, H., Schorn, R. A., Moore, R., Giver, L. P., and Smith, H. J., 1966, High-Dispersion Spectroscopic Observations of Mars I. The CO_2 Content and Surface Pressure, Ap.J., 146, 331-338

Schorn, R. A. and Gray, L. D., 1967, The Martian Surface Pressure, Ap.J., 148, 663

Barker, Edwin, 1967, A Determination of the Martian CO_2 Abundance, Ap.J., 147, 379-381

Bergstrahl, J. T., Gray, L. D., and Smith, H. J., 1967, An Upper Limit for Carbon Dioxide on Mercury, Ap.J., (Letter in Press)

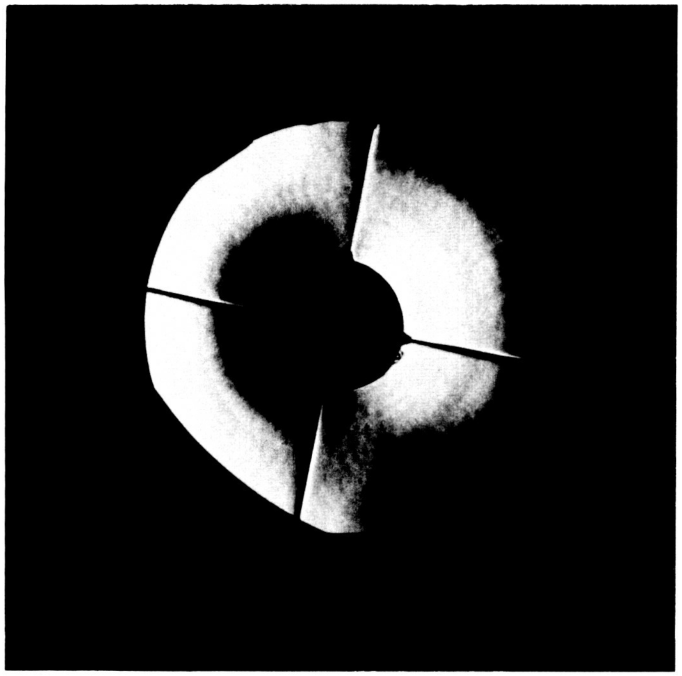
Gray, L. D. and Schorn, R. A., 1967, High Dispersion Spectroscopic Studies of Venus I. The Carbon Dioxide Bands Near 1 Micron, (Submitted to Icarus)

Owen, Tobias, 1967, Chemical Abundances in Planetary Atmospheres, Symposium on the Origin and Distribution of the Elements, (in press)

XI. Financial Report

The final billing for this contract is submitted by the Auditor's Office of The University of Texas.

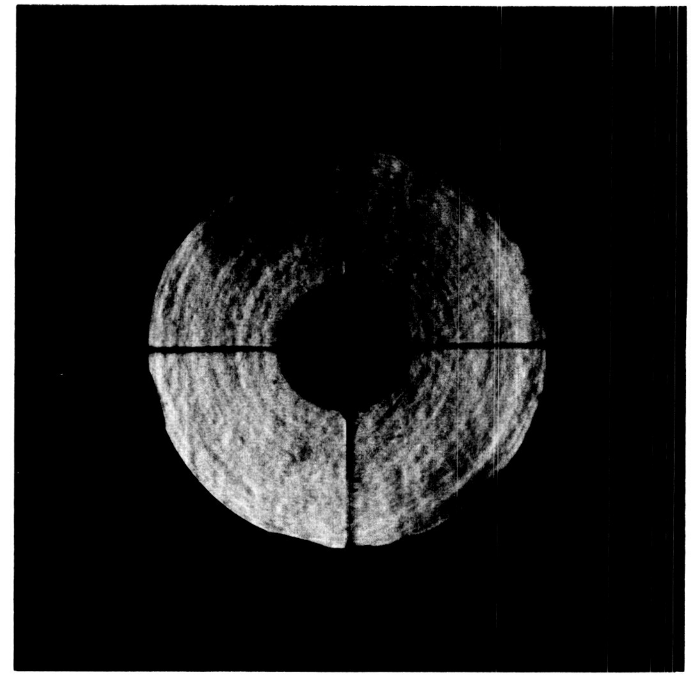
LIST OF PRINTS AND ILLUSTRATIONS



Foucaultgram showing condition of 82-inch coude optics prior to optical work by Texereau

August 17, 1964

State No. 0 Overcorrection 3.1 λ

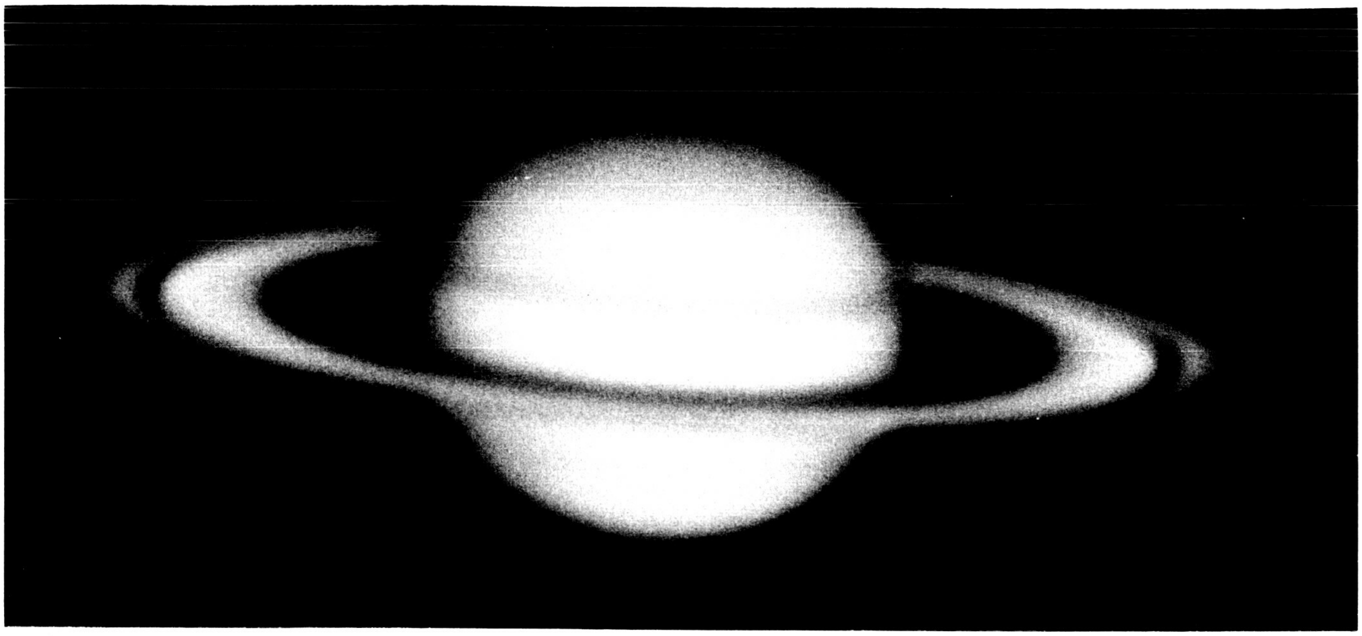


Foucaultgram showing condition of 82-inch coude optics after final correction by Texereau

September 16, 1964

State No. 21 21^h59^m

(Gray shadows on mirror arise from air currents in tube)



Saturn September 29, 1964

82-inch Coude + Barlow lens

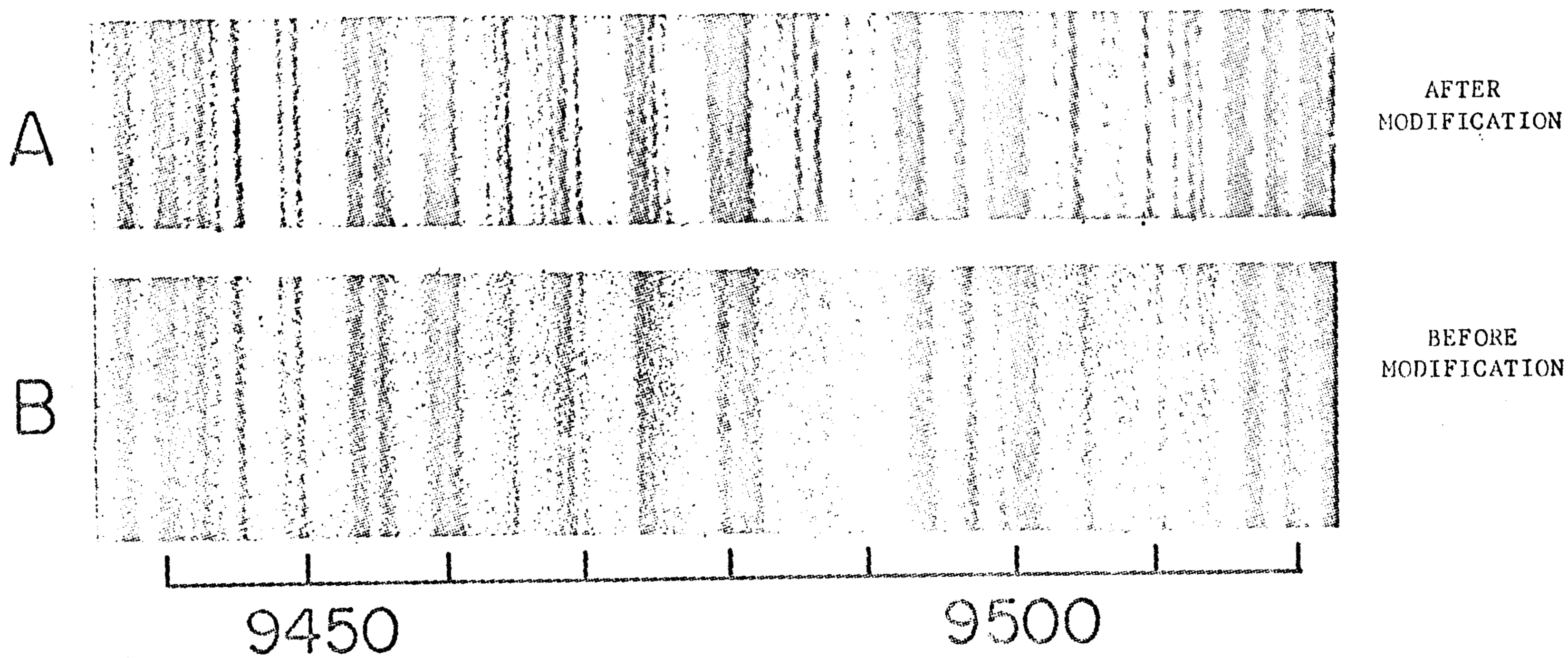
EFL: 153 meters x 4.9 enlargement of negative
Exposure: 1.5 sec. on Tri X

Double Star Σ 359; Separation $\rho = 0\overset{''}{.}49$

82-inch Coude + Barlow lens

EFL: 153 meters x 12 enlargement of negative
Scale on this print: 1" = 9 mm

SPEED AND RESOLUTION IMPROVEMENT IN COUDE SPECTROGRAPH

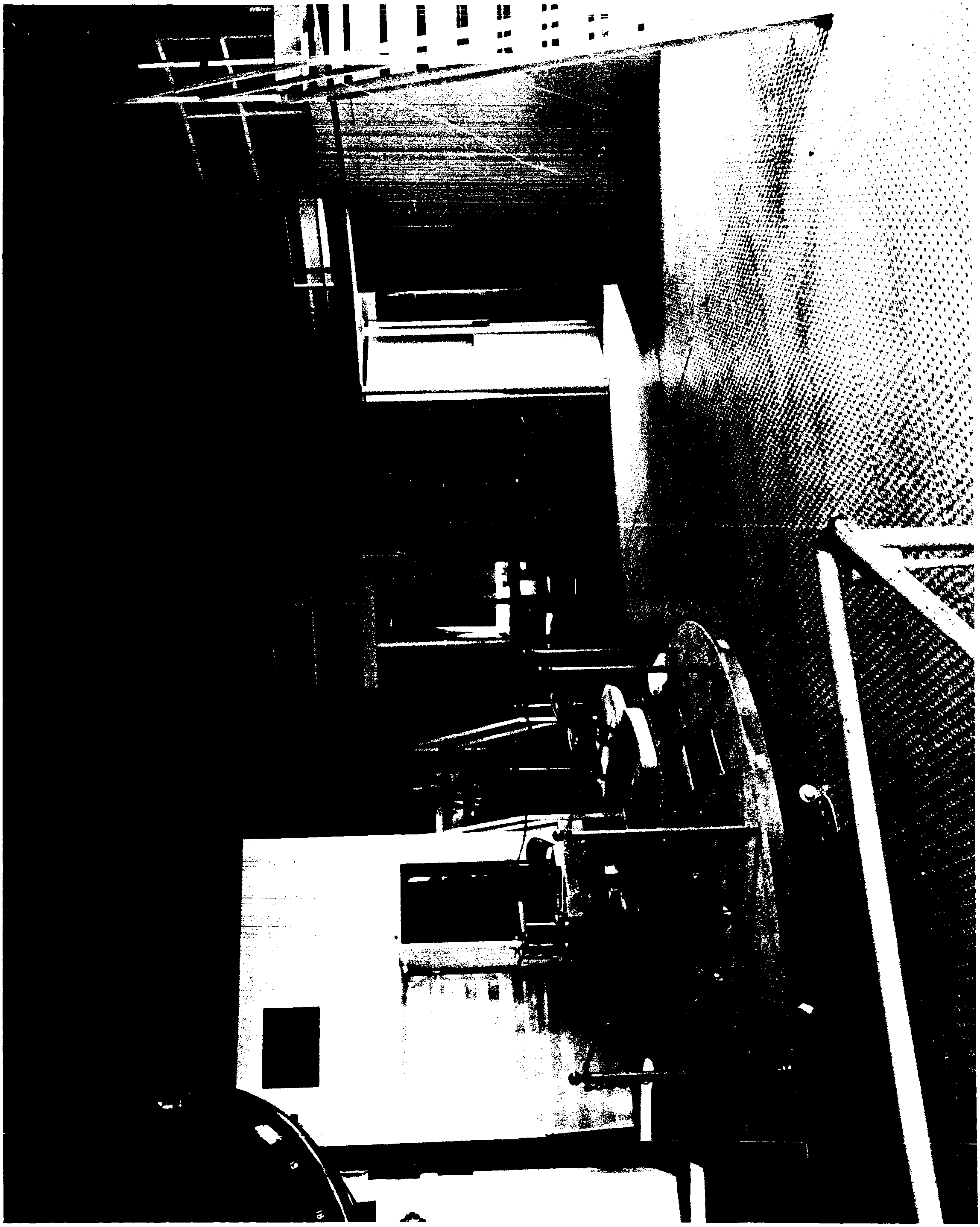


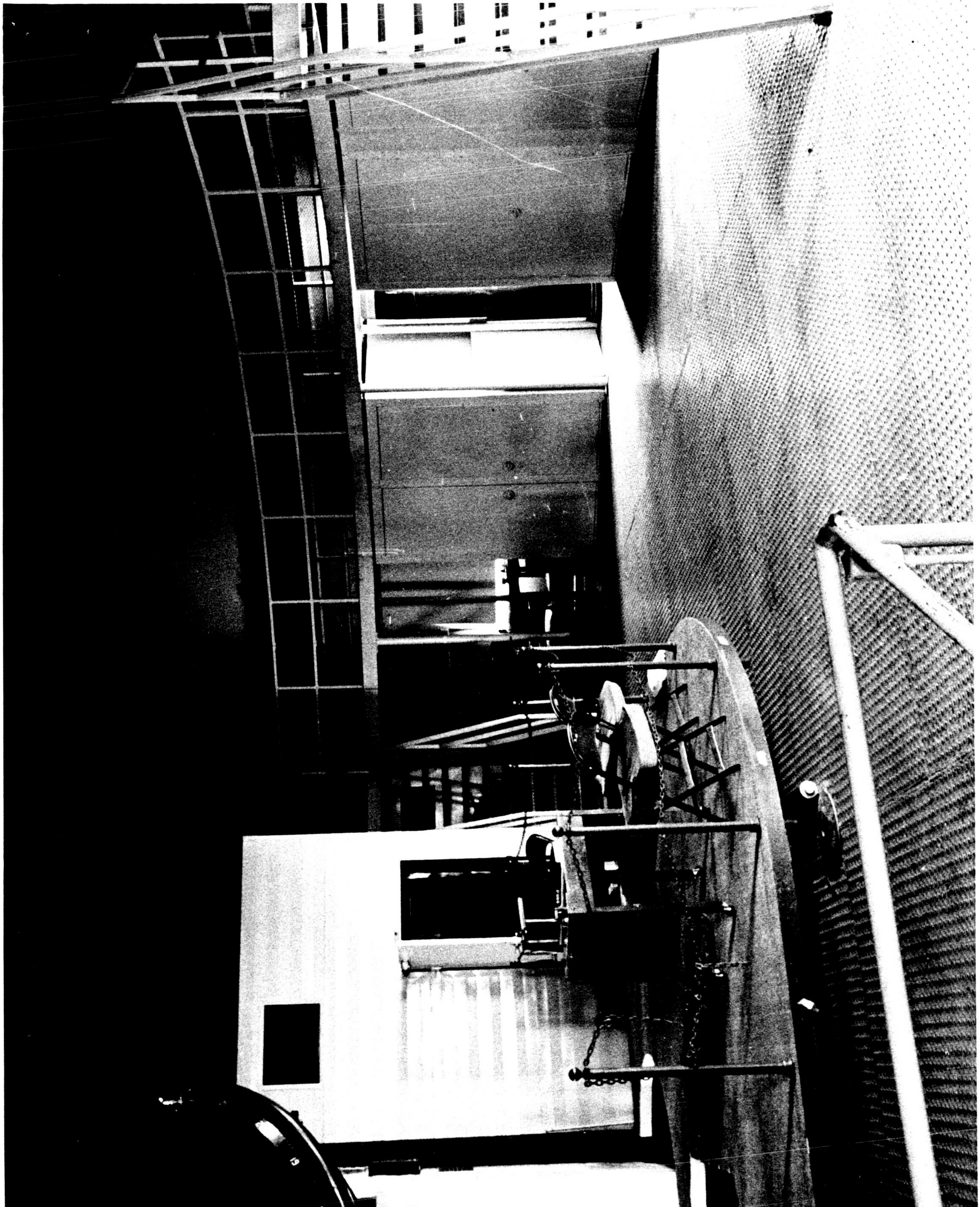
Spectra of the Moon: 9440-9520 Å

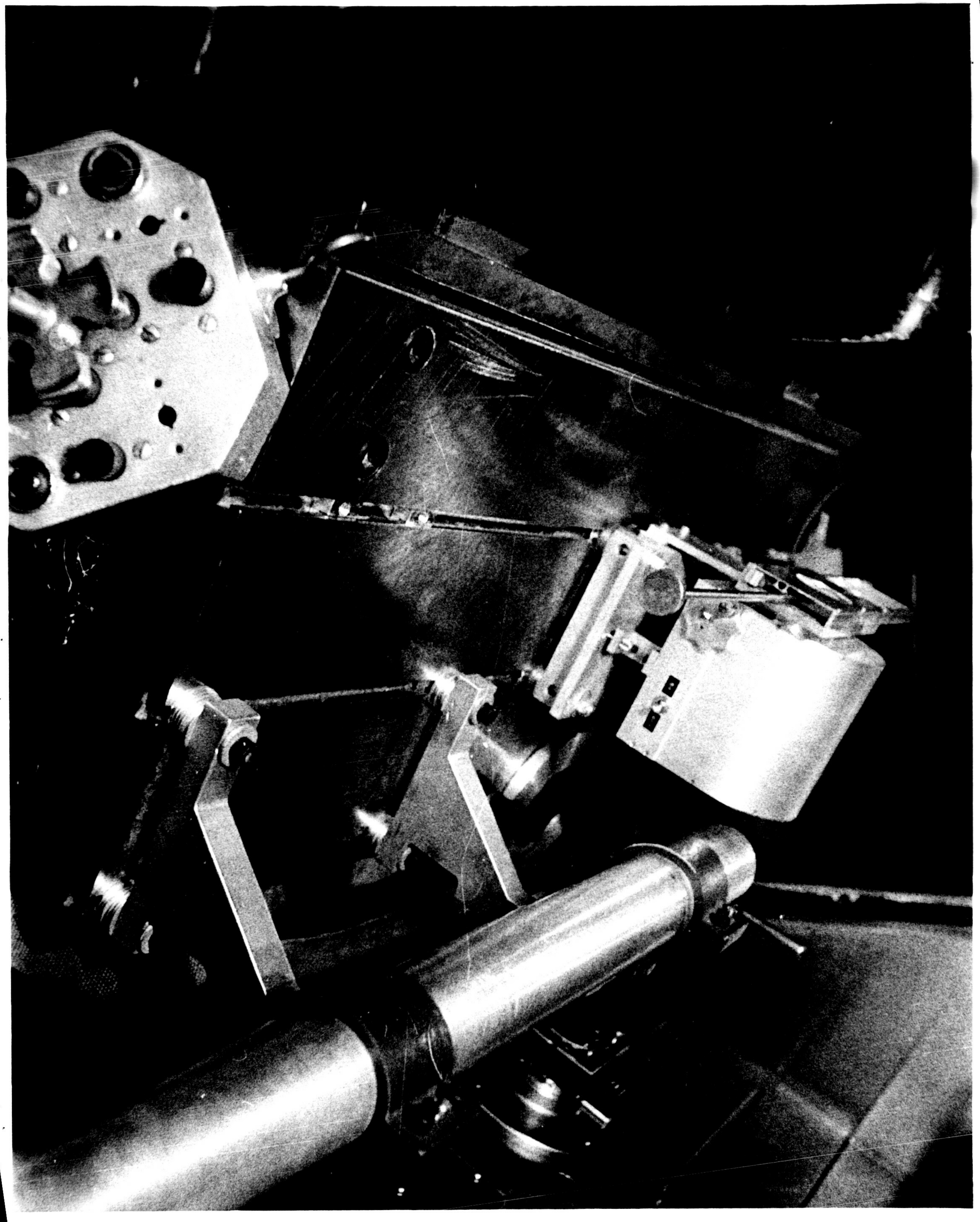
McDonald C Camera

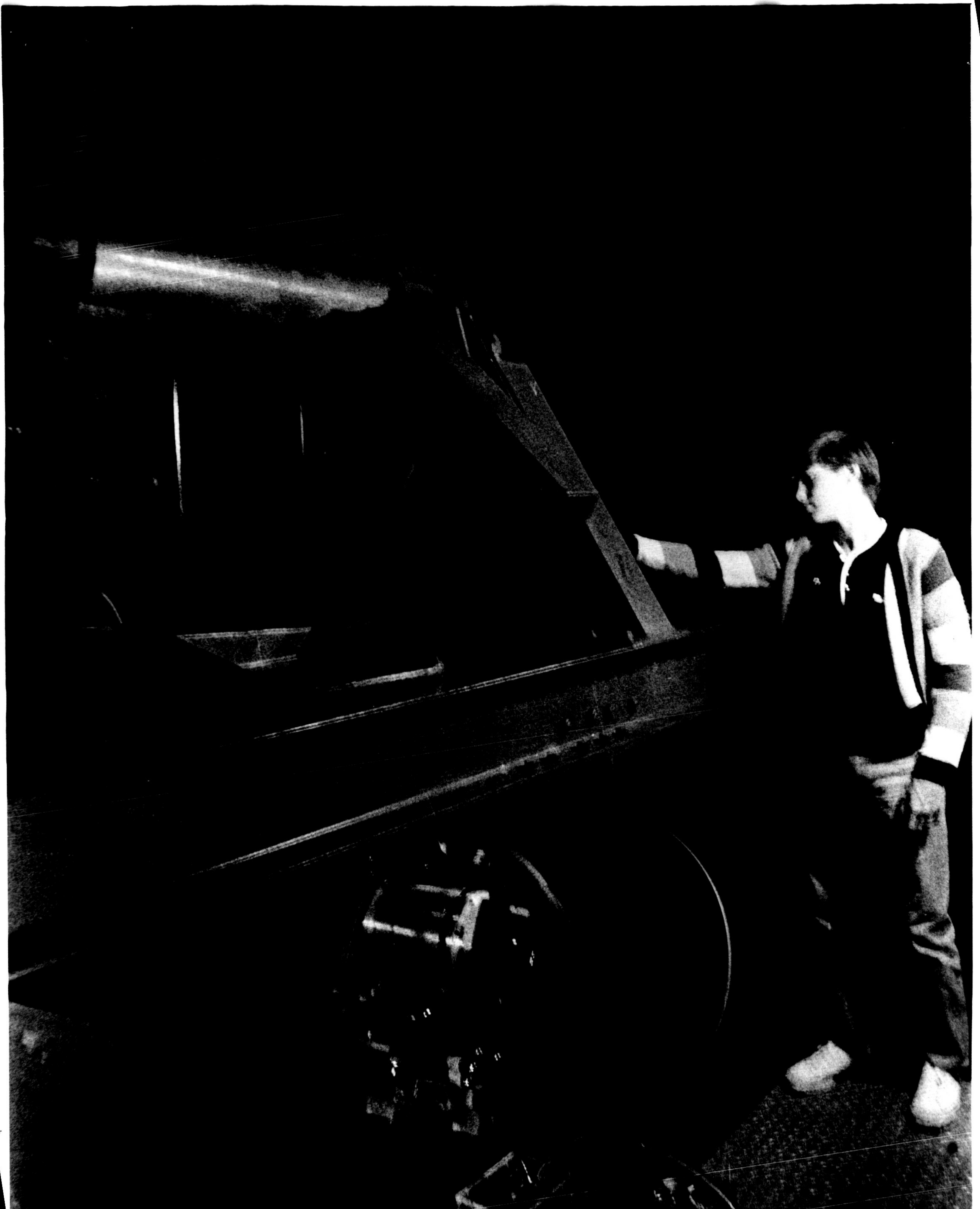
Hypersensitized I-M Emulsion

	<u>A</u>	<u>B</u>
Date	Nov. 22, 1966	Nov. 5, 1965
Slit	9/.150	10/.150
Exp.	15 min.	90 min.







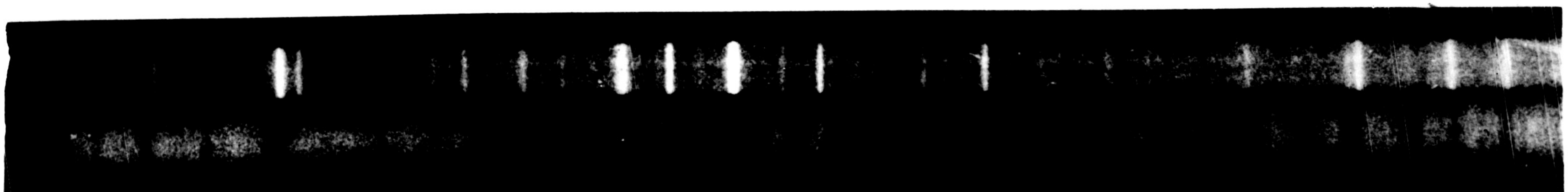


RCA-CARNEGIE S-1 IMAGE TUBE SPECTRUM OF VENUS

Effective exposure: about 2.5 hours on baked IIaO. Original dispersion: 3.25 Å per millimeter, using the coude spectrograph A camera of the McDonald 82-inch Struve Reflector - April 4, 1967.

Showing approximately 110 Å of spectrum centered around 12,200 Å. The strong band is of CO_2 in Venus, the band head around 12,178 Å; comparison lines are first, second, and third order iron arc. The spectrum of Venus was deliberately displaced to one side of the slit to allow any sky contamination to show up along the remaining slit length. The non-CO_2 lines are almost entirely terrestrial water vapor.

Resolution only approximately 0.5 Å; the present resolution limit is set mainly by transfer lens used to read out final image.



RCA-CARNEGIE S-1 IMAGE TUBE SPECTRUM OF VENUS

Effective exposure: about 45 minutes on baked IIaO. Original dispersion: 3.25 Å per millimeter, using the coude spectrograph A camera of the McDonald 82-inch Struve Reflector - April 3, 1967.

Showing approximately 130 Å of spectrum centered around 12,060 Å. The strong band is of CO_2 in Venus, the band head around 12,030 Å; comparison lines are first, second, and third order iron arc. The spectrum of Venus was deliberately displaced to one side of the slit to allow any sky contamination to show up along the remaining slit length. The non-CO_2 lines are almost entirely terrestrial water vapor.

Resolution only approximately 0.5 Å; the present resolution limit is set mainly by transfer lens used to read out final image.